

# ASYMPTOTIC METHODS

Prof. N. S. Manton

## Introduction

In this course, we will be interested in finding so-called *asymptotic series*, leading to approximations to the values of integrals depending on some parameter, or to the solutions of differential equations. For instance, consider *Stirling's Approximation*

$$n! \sim (2\pi n)^{1/2} \left(\frac{n}{e}\right)^n \quad \text{as } n \rightarrow \infty \quad \text{or} \quad \Gamma(n) = (n-1)! \sim \left(\frac{2\pi}{n}\right)^{1/2} \left(\frac{n}{e}\right)^n$$

We will also be interested in the *Stieltjes Integral*: let  $\rho(t)$  be a well-behaved non-negative function that decays sufficiently fast as  $t \rightarrow \infty$ . Then

$$\int_a^\infty \frac{\rho(t)}{1+xt} dt \sim \int_a^\infty \rho(t) dt \quad \text{for small } x > 0$$

The *modified Bessel function of order zero*,  $I_0$ , solves the differential equation

$$\frac{d^2 y}{dx^2} + \frac{1}{x} \frac{dy}{dx} - y = 0$$

and has the following expansion with infinite radius of convergence:

$$I_0(x) = \sum_{n=0}^{\infty} \frac{x^{2n}}{2^{2n}(n!)^2} \sim (2\pi x)^{-1/2} e^x \quad \text{as } x \rightarrow \infty$$

Asymptotic expansions are widely used in applied mathematics and theoretical physics, e.g. when deriving the leading-order contribution to the electrostatic potential corresponding to a charge distribution of limited spatial extent when viewed from far away. In number theory, the prime number theorem states that the number  $\pi(n)$  of primes at most  $n$  satisfies  $\pi(n) \sim \frac{n}{\ln n}$  as  $n \rightarrow \infty$ .

In the above examples, the symbol  $\sim$  means that the ratio of the two sides tends to unity in the appropriate limit. If we seek better approximations, we can derive *asymptotic series*, such as the Stirling series

$$\Gamma(n) \sim \left(\frac{2\pi}{n}\right)^{1/2} \left(\frac{n}{e}\right)^n \left[1 + \frac{1}{12n} + \frac{1}{2880n^2} + \dots\right]$$

where the coefficients are known, but not elementary. The coefficients get smaller for a while, but eventually grow rapidly. The series does not converge for any  $n$ . Upon truncating, this series gives a sequence of approximations:

$$\frac{\Gamma(n)}{\left(\frac{2\pi}{n}\right)^{1/2} \left(\frac{n}{e}\right)^n} - 1 = o(1), \quad \frac{\Gamma(n)}{\left(\frac{2\pi}{n}\right)^{1/2} \left(\frac{n}{e}\right)^n} - 1 - \frac{1}{12n} = o\left(\frac{1}{n}\right), \quad \dots \quad \text{for large } n$$

For  $n = 4$ , these approximations give  $3! = 5.877$  and  $3! = 5.999$ . For  $n = 4$ , the approximation using six terms gives the best answer; with more terms, the error increases, since the series does not converge.

For the Stieltjes integral, we will show that, using the Taylor expansion  $(1+xt)^{-1} = 1 - xt + x^2 t^2 + \dots$  valid for  $t < 1/x$ ,

$$\int_a^\infty \frac{\rho(t)}{1+xt} dt \sim \sum_{n=0}^{\infty} (-1)^n c_n x^n \quad \text{where } c_n = \int_a^\infty t^n \rho(t) dt$$

# Asymptotic Methods In Analysis

**Nicolas Govert de Bruyn**



## **Asymptotic Methods In Analysis:**

**Asymptotic Methods in Analysis** N. G. de Bruijn, 2014-03-05 This pioneering study textbook in a crucial area of pure and applied mathematics features worked examples instead of the formulation of general theorems Extensive coverage of saddle point method iteration and more 1958 edition

**Asymptotic Methods For Integrals** Nico M Temme, 2014-10-31 This book gives introductory chapters on the classical basic and standard methods for asymptotic analysis such as Watson's lemma Laplace's method the saddle point and steepest descent methods stationary phase and Darboux's method The methods explained in great detail will obtain asymptotic approximations of the well known special functions of mathematical physics and probability theory After these introductory chapters the methods of uniform asymptotic analysis are described in which several parameters have influence on typical phenomena turning points and transition points coinciding saddle and singularities In all these examples the special functions are indicated that describe the peculiar behavior of the integrals The text extensively covers the classical methods with an emphasis on how to obtain expansions and how to use the results for numerical methods in particular for approximating special functions In this way we work with a computational mind how can we use certain expansions in numerical analysis and in computer programs how can we compute coefficients and so on

*Applied Asymptotic Analysis* Peter David Miller, 2006 This book is a survey of asymptotic methods set in the current applied research context of wave propagation It stresses rigorous analysis in addition to formal manipulations Asymptotic expansions developed in the text are justified rigorously and students are shown how to obtain solid error estimates for asymptotic formulae The book relates examples and exercises to subjects of current research interest such as the problem of locating the zeros of Taylor polynomials of entire nonvanishing functions and the problem of counting integer lattice points in subsets of the plane with various geometrical properties of the boundary The book is intended for a beginning graduate course on asymptotic analysis in applied mathematics and is aimed at students of pure and applied mathematics as well as science and engineering The basic prerequisite is a background in differential equations linear algebra advanced calculus and complex variables at the level of introductory undergraduate courses on these subjects The book is ideally suited to the needs of a graduate student who on the one hand wants to learn basic applied mathematics and on the other wants to understand what is needed to make the various arguments rigorous Down here in the Village this is known as the Courant point of view Percy Deift Courant Institute New York Peter D Miller is an associate professor of mathematics at the University of Michigan at Ann Arbor He earned a Ph D in Applied Mathematics from the University of Arizona and has held positions at the Australian National University Canberra and Monash University Melbourne His current research interests lie in singular limits for integrable systems

**Asymptotic Methods in Analysis** Nicolaas Govert Bruijn, 1958

**Asymptotic Analysis** J.D. Murray, 2012-12-06 From the reviews A good introduction to a subject important for its capacity to circumvent theoretical and practical obstacles and therefore particularly prized in the applications of mathematics The book presents a

balanced view of the methods and their usefulness integrals on the real line and in the complex plane which arise in different contexts and solutions of differential equations not expressible as integrals Murray includes both historical remarks and references to sources or other more complete treatments More useful as a guide for self study than as a reference work it is accessible to any upperclass mathematics undergraduate Some exercises and a short bibliography included Even with E T Copson s *Asymptotic Expansions* or N G de Bruijn s *Asymptotic Methods in Analysis* 1958 any academic library would do well to have this excellent introduction S Puckette University of the South Choice Sept 1984 1 [Asymptotic methods in analysis](#) Nicolas Govert de Bruyn,1958 *Introduction to Asymptotic Methods* David Y. Gao,Vadim A. Krysko,2006-05-03 Among the theoretical methods for solving many problems of applied mathematics physics and technology asymptotic methods often provide results that lead to obtaining more effective algorithms of numerical evaluation Presenting the mathematical methods of perturbation theory Introduction to Asymptotic Methods reviews the most important m **Asymptotic Methods for Integrals** Nico M. Temme,2015 This book gives introductory chapters on the classical basic and standard methods for asymptotic analysis such as Watson s lemma Laplace s method the saddle point and steepest descent methods stationary phase and Darboux s method The methods explained in great detail will obtain asymptotic approximations of the well known special functions of mathematical physics and probability theory After these introductory chapters the methods of uniform asymptotic analysis are described in which several parameters have influence on typical phenomena turning points and transition points coinciding saddle and singularities In all these examples the special functions are indicated that describe the peculiar behavior of the integrals The text extensively covers the classical methods with an emphasis on how to obtain expansions and how to use the results for numerical methods in particular for approximating special functions In this way we work with a computational mind how can we use certain expansions in numerical analysis and in computer programs how can we compute coefficients and so on [Asymptotic Methods in Analysis. 2nd Ed](#) Nicolaas Govert Bruijn,1958

**Techniques of Asymptotic Analysis** Lawrence Sirovich,2013-12-01 These notes originate from a one semester course which forms part of the Math Methods cycle at Brown In the hope that these notes might prove useful for reference purposes several additional sections have been included and also a table of contents and index Although asymptotic analysis is now enjoying a period of great vitality these notes do not reflect a research oriented course The course is aimed toward people in applied mathematics physics engineering etc who have a need for asymptotic analysis in their work The choice of subjects has been largely dictated by the likelihood of application Also abstraction and generality have not been pursued Technique and computation are given equal prominence with theory Both rigorous and formal theory is presented very often in tandem In practice the means for a rigorous analysis are not always available For this reason a goal has been the cultivation of mature formal reasoning Therefore during the course of lectures formal presentations gradually eclipse rigorous presentations When this occurs rigorous proofs are given as exercises or in the case of lengthy proofs reference is made to

the Reading List at the end

*Analysis I* Revaz V. Gamkrelidze, 2012-12-06 Infinite series and their analogues integral representations became fundamental tools in mathematical analysis starting in the second half of the seventeenth century They have provided the means for introducing into analysis all of the so called transcendental functions including those which are now called elementary the logarithm exponential and trigonometric functions With their help the solutions of many differential equations both ordinary and partial have been found In fact the whole development of mathematical analysis from Newton up to the end of the nineteenth century was in the closest way connected with the development of the apparatus of series and integral representations Moreover many abstract divisions of mathematics for example functional analysis arose and were developed in order to study series In the development of the theory of series two basic directions can be singled out One is the justification of operations with infinite series the other is the creation of techniques for using series in the solution of mathematical and applied problems Both directions have developed in parallel Initially progress in the first direction was significantly smaller but in the end progress in the second direction has always turned out to be of greater difficulty

*Asymptotic Methods in Analysis and Combinatorics*, 1992 *Asymptotic Analysis of Differential Equations* R. B. White, 2010 This is a useful volume in which a wide selection of asymptotic techniques is clearly presented in a form suitable for both applied mathematicians and Physicists who require an introduction to asymptotic techniques Book Jacket

*Advanced Mathematical Methods for Scientists and Engineers I* Carl M. Bender, Steven A. Orszag, 2013-03-09 The triumphant vindication of bold theories are these not the pride and justification of our life's work Sherlock Holmes The Valley of Fear Sir Arthur Conan Doyle The main purpose of our book is to present and explain mathematical methods for obtaining approximate analytical solutions to differential and difference equations that cannot be solved exactly Our objective is to help young and also established scientists and engineers to build the skills necessary to analyze equations that they encounter in their work Our presentation is aimed at developing the insights and techniques that are most useful for attacking new problems We do not emphasize special methods and tricks which work only for the classical transcendental functions we do not dwell on equations whose exact solutions are known The mathematical methods discussed in this book are known collectively as asymptotic and perturbative analysis These are the most useful and powerful methods for finding approximate solutions to equations but they are difficult to justify rigorously Thus we concentrate on the most fruitful aspect of applied analysis namely obtaining the answer We stress care but not rigor To explain our approach we compare our goals with those of a freshman calculus course A beginning calculus course is considered successful if the students have learned how to solve problems using calculus

**Asymptotic Analysis** Mikhail Vasil'evich Fedoruk, 1993 In this book we present the main results on the asymptotic theory of ordinary linear differential equations and systems where there is a small parameter in the higher derivatives We are concerned with the behaviour of solutions with respect to the parameter and for large values of the independent variable The literature on this question is considerable and widely dispersed but the methods of proofs are

sufficiently similar for this material to be put together as a reference book We have restricted ourselves to homogeneous equations The asymptotic behaviour of an inhomogeneous equation can be obtained from the asymptotic behaviour of the corresponding fundamental system of solutions by applying methods for deriving asymptotic bounds on the relevant integrals We systematically use the concept of an asymptotic expansion details of which can if necessary be found in Wasow 2 Olver 6 By the formal asymptotic solution  $FAS$  is understood a function which satisfies the equation to some degree of accuracy Although this concept is not precisely defined its meaning is always clear from the context We also note that the term Stokes line used in the book is equivalent to the term anti Stokes line employed in the physics literature

Introduction to Asymptotics Douglas Samuel Jones, 1997 A very attractive feature of the book is the numerous examples illustrating the methods A fine collection of exercises enriches each chapter challenging the reader to check his progress in understanding the methods Mathematical Reviews As an introductory book to asymptotics with chapters on uniform asymptotics and exponential asymptotics this book clearly fills a gap it has a friendly size and contains many convincing numerical examples and interesting exercises Hence I recommend the book to everyone who works in asymptotics SIAM 1998 it is an excellent book that contains interesting results and methods for the researchers It will be useful for the students interested in analysis and lectures on asymptotic methods The reviewer recommends the book to everyone who is interested in analysis engineers and specialists in ODE s Acta Sci Math Szeged 1999

Asymptotic Analysis J.D. Murray, 1992-02-02 From the reviews A good introduction to a subject important for its capacity to circumvent theoretical and practical obstacles and therefore particularly prized in the applications of mathematics The book presents a balanced view of the methods and their usefulness integrals on the real line and in the complex plane which arise in different contexts and solutions of differential equations not expressible as integrals Murray includes both historical remarks and references to sources or other more complete treatments More useful as a guide for self study than as a reference work it is accessible to any upperclass mathematics undergraduate Some exercises and a short bibliography included Even with E T Copson s Asymptotic Expansions or N G de Bruijn s Asymptotic Methods in Analysis 1958 any academic library would do well to have this excellent introduction S Puckette University of the South Choice Sept 1984 1

Introduction To Asymptotics - A Treatment Using Nonstandard Analysis Douglas S Jones, 1997-01-16 Many branches of science and engineering involve applications of mathematical analysis An important part of applied analysis is asymptotic approximation which is therefore an active area of research with new methods and publications being found constantly This book gives an introduction to the subject sufficient for scientists and engineers to grasp the fundamental techniques both those which have been known for some time and those which have been discovered more recently The asymptotic approximation of both integrals and differential equations is discussed and the discussion includes hyperasymptotics as well as uniform asymptotics There are many numerical examples to illustrate the relation between theory and practice Exercises in the chapters enable the book to be used as a text for an introductory

course *Analysis I*, 1989  
Grebenikov, 1983

*Constructive Methods in the Analysis of Nonlinear Systems* Evgenii Aleksandrovich

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